

A comparative study of the denoising methods of Thematic Mapper images for forest areas

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Abstract: The noises of remote sensing images, caused by imaging system and ground environment, negatively affect the accuracy and efficiency in extracting forest information from remote sensing images. The denoising is critical for image classifications for forest areas. The objective of this research is to assess the effectiveness of currently used spatial filtering methods for extracting with forest information related from Landsat 5 TM images. Five spatial filtering methods including low-pass filter, median filter, mean filter, sigma filter and enhanced self-adaptive filter were examined. A set of evaluation indices was designed to assess the ability of each denoising method for flatness, edge/boundary retention and enhancement. Based on the designed evaluation indices and visual assessment, it was found that sigma filter ($D=1$) and enhanced self-adaptive filter were the most effective denoising methods in classifying TM images for forest areas.

Keywords: Denoising; Edge/boundary retention; Enhanced self-adaptive filter; TM image

Introduction

Remote sensing images are widely used for resource assessment, environment monitoring, geological survey, land mapping, disaster warning and assessment (Cibula *et al.* 1987; Aikenhead *et al.* 2004). Forest inventory is critical for sustainable forest management, however, it is expensive and time-consuming. Remote sensing images provide inexpensive alternatives for resource monitoring across large forest areas. Previous researches indicated that remote sensing image system could be used to extract forest information. For example, Rigina (1999) successfully detected the boreal forest decline around the Severonikel Smelter for the period 1964–1996 through spectral change patterns with high-resolution satellite images, such as Corona spy satellite images (2m resolution) and IRS 1C panchromatic images (5m resolution). Thematic Mapper (TM) images have also been used for forest resource surveys (Skidmore 1989; Bolstad *et al.*; 1992; Gross 1999; Yang 2002). Liu *et al.* (2004) successfully used DEM combined with Landsat TM to divide supervise-classify forest areas into five forest types (shrub, broadleaf, mixed leaf, dark needle and short tree). Maribeth *et al.* (2002) investigated forest resources and simulated the growing environment with Landsat TM images. They developed a remote sensing method that could be used to establish and maintain a forest inventory database in a cost-effective manner.

However, the noises in TM image system sometimes limit the images' application, especially in forest areas. There are two

major sources for noises in TM image system of forest areas: the imaging system noise and ground environment noise. The system noises come from thematic map sensor when the images are taken. These include photo-electronic noise, particle of plate noise and electronic noise. Ground environment noises are affected by the reflective characteristics of forest areas. For example, shadow effects caused by high-relief terrain would affect reflective values of TM images. Furthermore, the results of TM images (30m) are considered to be coarse. The value of image pixel is inevitably disturbed by neighboring plant, especially in mixed broad-needle leaved forest areas. The phenomena of "same spectrum but different things" and "same things but different spectrum" happened frequently. All these noises would negatively affect the accuracy and efficiency of image classification. For example, Yue (2004) attempted to use TM images to classify forest types in Jinshajiang Drainage Basin, and only obtained 61% in classification precision. At present, noise reduction is still a major issue that limits the use of TM images in forest areas.

Many research efforts have been made to reduce noise for remote sensing images, and a number of denoising methods have been developed in the past years. Mueller *et al.* (1987), Morial (1995), Rio and Olsson (2000) presented a median filter algorithm to denoise the RADARSAT images. Weng *et al.* (2001) developed Mallat algorithm, Smolkaa *et al.* (2002) developed a self-adaptive algorithm, Samuel Morillas *et al.* (2005) developed fuzzy metric algorithm, Delouille (2005) developed a second-generation wavelet denoising method. All these denoising methods were developed for specific purposes and most of them were used for color images. There are few researches to evaluate the effectiveness of these denoising methods by using TM images for classifying forest types.

In this research, the authors evaluated the effectiveness of nine different spatial filter treatments based on low-pass filter, median filter, mean filter, sigma filter and enhanced self-adaptive filter. The authors also designed a set of evaluation indexes to assess the effectiveness of the denoising methods. A comparative experiment was conducted in Wangqing Forest Bureau, China, to

Received: 2006-07-10; Accepted: 2006-09-27

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Electronic supplementary material is available in the online version of this article at <http://dx.doi.org/10.1007/s11676-007-0024-x>

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Responsible editor: Zhu Hong

identify the most suitable denoising method by using Landsat TM for forest type classification.

Methods

Study site and image acquisition

Study site is located in middle and low mountainous region of Changbai Mountain (129°56′–131°04′ E, 43°05′–43°40′ N), and managed by Wangqing Forest Bureau, Jilin, China, with elevation ranging from 360 m to 1477 m. There are three large rivers in this region with steep terrain and various vegetations on both sides. Forest types are mainly mixed broadleaved and coniferous forests that are representative in north-east forest areas of China. The main broadleaved tree species are *T. amurensis* Rapr., *Quercus mongolica* Fisch, *Acer mono*, *Betula platyphylla* and *Betula costata*. Middle age stands are the major parts. The structure of forest community changes with elevation and the forest diversity reduces with decrease of elevation (Chang *et al.* 2003, Jiang *et al.* 2003). When the terrain, vegetation and climate condition change, the distribution of soil type also changes. The major soil type is dark-brown earth, and the rests are peat soils and meadow soils. TM images of Landsat 5 satellite were acquired on July 11, 1997. The images have 7 bands images with spatial resolutions of 30 m in the 1–5, 7th band, and 120 m in the 6th band. In this study, three bands (TM4=R, TM3=G, TM2=B) are adopted to color composite for improving color resolution, because the fake color combination always shows the most vegetation information of TM images (Mei *et al.* 2001).

Proposed denoising method

Five filtering methods were tested, including low-pass filter, sigma filter, mean filter, median filter and enhanced self-adaptive filter. Enhanced self-adaptive filter was constructed by Model-Maker of IMAGINE software (reference the algorithm of Dang, 2003). Other four methods were built in functions of ERDAS software.

The low-pass filter method was developed by Seyrafi in 1964. It is basically a Fourier transformation. TM images are transformed from space domain to frequency domain. In frequency domain, it is the general rules that the low frequency values are useful signals and high frequency values are noises and should be filtered out. The images are getting smooth after removing high frequency noises.

Sigma filter, mean filter and median filter methods belong to statistic filter method (Tang *et al.* 1996; Weng *et al.* 2001; Vardavoulia *et al.* 2001). In the processes, the value of each pixel was modified using the statistics values (sigma values, mean, and median) in a squared window surrounding the pixel to be processed. The median filter method uses the medial value in an odd number squared window. The mean filter method uses the mean value of 4 or 8 neighboring pixels to alter original pixel value. The sigma filter method uses the sigma parameter which is counted in an odd number squares window. The sigma filter method has different denoised effects to image if the values of multiplying sigma parameter n are different (Equation (1)).

$$D_v' = D_v \pm SiD \quad (1)$$

where, $Si = \sqrt{V}/M$, D_v' is the denoised pixel values, D_v the original pixel values, D the enhance parameter; V the squared deviation of squared window, M the mean of squared window.

Enhanced self-adaptive filter method is an improved frost self-adaptive filter method (Du 2002; Smolkaa 2002). A power parameter W was decided first by Equation (2). The parameter A was gained based on Equation (3). Then denoised pixel value D_v' could be determined by Equation (4).

$$W = \exp(-A_T) \quad (2)$$

$$A = \begin{cases} M & (C_x < C_u) \\ D(C_x - C_u)/(C_{\max} - C_x) & (C_u \leq C_x \leq C_{\max}) \\ D_{V_{ij}} & (C_x > C_{\max}) \end{cases} \quad (3)$$

$$D_v'(i,j) = \frac{\sum_{k=i-n}^{i+n} \sum_{l=j-n}^{j+n} D_{V_{kl}} W_{kl}}{\sum_{k=i-n}^{i+n} \sum_{l=j-n}^{j+n} W_{kl}} \quad (4)$$

where, W is the power parameter, T the absolute distance from the center pixel of squared windows to neighbor pixel, $C_x = V/M$ the relative standard deviation of squared window, $C_u = \sigma_u/\mu$ the relative standard deviation of noise, σ_u the squared deviation of noise, μ the mean of noise (Xu *et al.* 1999; Li *et al.* 2000), $C_{\max} = \sqrt{3}C_u$, and n is the radius of squared window.

Experiment methods

Contrastive experiments were used to evaluate the effectiveness of five denoising methods. Nine schemes were chosen based on the filtering method and their parameters. For low-pass filter, the round filter radius was 50; for sigma filter, squared window was 5 cells by 5 cells and D was 1 and 4; for the adaptive filter, enhanced frost algorithm was used; for median filter, squared windows were 3 cells by 3 cells, 5 cells by 5 cells and 7 cells by 7 cells; for mean filter, neighborhood sizes were 4 cells and 8 cells.

Evaluation indexes

A group of evaluation indexes in combination with visual assessment were used to evaluate the effectiveness of the nine schemes. The evaluation indices including: Flatness Ratio Index (F_{RI}), Edge Keep Ratio Index (E_{KRI}), Peak Signal Noise Ratio Index (P_{SNR}), Integrated $F_{RI} - E_{KRI} - P_{SNRI}$ Index (F_{EP}).

F_{RI} was used to calculate the ratio of flatness parameters before and after filtering in Equation (5). It shows the ability of smoothness in each filtering methods. The greater the value of F_{RI} is, the higher the ability of smoothness is.

$$F_{RI} = F_I' / F_I \quad (5)$$

where, $F_I = M/S_D$; F_I is the flatness parameter before filtering; F_I' the flatness parameter after filtering. S_D ---- the standard deviation E_{KRI} were to measure the ability of maintaining and enhancing the edge/boundary information for TM images in various denoising method (Zhu 2003). The greater the value of E_{KRI} is, the better the edge holding ability is. The equation is as follows:

$$E_{KRI} = T / T' \quad (6)$$

where, $T = \frac{\sum_{j=1}^L (I_h(j) - I_l(j))}{\sum_{j=1}^L I_h(j) - \sum_{j=1}^L I_l(j)}$ edge holding ability parameter after

filtering, $I_h(j)$ is the pixel value of bright sides in edge/boundary after filtering, $I_l(j)$ is the pixel value of dark sides in edge/boundary after filtering; L the length of the edge. T' the edge holding ability parameter of original image.

The P_{SNR} index is used to evaluate the quality of the images. Its mathematic expression is:

$$P_{SNR} = 10 \log \frac{255^2}{\frac{1}{N \times N} \sum_{m=0}^{N-1} \sum_{n=0}^{N-1} (D_{Nmn} - D_{N' mn})^2} \quad (7)$$

where, N is the size of image.

Generally, when the value of P_{SNR} is greater than 30, the images after filtering have good quality and with little difference from original images (Xu 2002). Therefore, the P_{SNR} can be used to reflect the change of P_{SNR} , the equation is:

$$P_{SNR} = P_{SNR} / 30 \quad (8)$$

A composite index F_{EP} is calculated based on three other indices with different weights in Equation (9).

$$F_{EP} = aF_{RI} + bE_{KRI} + cP_{SNRI} \quad (9)$$

where, $a + b + c = 1$. Parameters a , b and c , could be adjusted based to special objectives.

Data analysis

In Table 1, the values F_{RI} of images processed by six denoising schemes are greater than that of original images, which means that these schemes had smoothed out the original images and eliminated high frequency noises in systems. Data indicates that median filter, low-pass filter, sigma filter and self-adaptive filter are good denoising methods for TM images in large forest areas.

However, to residential areas and roads, over-flattening might cause inaccurate object identification and image classification. One reason is that residential areas and roads had some texture information in TM image due to the dense and orderly arrangement. Another possible reason could be the small and scattered distribution of these structures in TM images. Over-flattening will destruct the texture information and ignore the small and scattered, which are big disadvantages of distinguishing objects

in TM images. For example, in Table 1, the value of F_{RI} after denoising by median filter (7×7) is much higher than that of original images. The roads and boundary of residential areas became blurry after denoising (Fig. 1), which is unfavorable for denosing processes. Information for residential areas and roads could possibly be lost through the filtering processes. Mathematically, median filter method is to replace the center pixel (current pixel) value by the median value of the squared windows. If the current pixel do not contain the noise and its value is not equal to the value of median, the original information at this pixel of TM images will be filtered out. Therefore, some information lost is inevitable during denoising.

Table 1. F_{RI} value in different filter methods

Denoising Method	F_{RI}			
	Mixed Forest	Broad leaf	Conifer	other land ¹⁾
Original Image	1.00	1.00	1.00	1.00
low-pass filter	1.59	1.36	1.28	1.59
sigma filter ($D=1$)	1.60	1.23	1.24	1.17
sigma filter ($D=4$)	1.60	1.24	1.24	1.30
Self-Ada. filter	1.60	1.24	1.24	1.24
Med. filter (3×3^2)	1.31	1.15	1.17	1.12
Med. filter (5×5)	1.55	1.30	1.33	1.27
Med. filter (7×7)	2.20	1.38	1.35	1.49
mean filter (4)	1.22	1.10	1.13	1.06
mean filter (8)	1.32	1.16	1.14	1.14

Notes: 1) Other land included residential area and roads. 2) It means that the squared window is 3 cells by 3 cells.

Table 2. E_{KRI} , P_{SNR} and F_{EP} values of different filter methods

Denoising Method	I_{FRI}	E_{KRI}	P_{SNRI}	F_{EP}
Original image	1.00	1.00	1.00	1.00
Low-pass filter	1.52	0.51	0.87	1.05
Sigma filter ($D=1$)	1.25	1.13	1.25	1.20
Sigma filter ($D=4$)	1.32	0.68	1.12	1.04
Self-Adapted filter	1.29	0.85	1.12	1.10
Med. Filter (3×3)	1.15	0.85	1.29	1.04
Med. filter (5×5)	1.32	0.57	1.14	1.00
Med. filter (7×7)	1.55	0.51	1.07	1.08
Mean filter (4)	1.10	0.88	1.35	1.04
Mean filter (8)	1.17	0.54	1.26	0.93
Mean	1.30	0.75	1.15	1.05

How to evaluate the optimal flatness ability of these filter methods became a big issue. The optimal method should be able to reduce or eliminate the noise in the TM image system from large forest areas while well retaining the fine details of images for highly fragmented land areas such as residential areas. An integrated index, Integrative flatness ratio index (I_{FRI}) was introduced in this study. To enhance the flattening results without losing too much information, an adjustment factor was used with 0.4 for the forest areas (F_{RI_f}) and 0.6 for other land areas (F_{RI_o}) in Equation (10). The best value should be the mean filter method. The images could be over-flattened if the value is greater than the mean and vice versa. Based on Table 2, the I_{FRI} value of self-adapted filter ($I_{FRI}=1.29$) is the closest to the

mean filter ($I_{FRI}=1.30$), so it is the optimal flatness filter method to TM images for forest areas. Mathematically, self-adapted filter adjusts parameters according to the environment (the relative standard deviation of squared window), so this filter can decrease the noise and hold on the suitable details of highly fragmented land areas.

$$I_{FRI} = 0.4 \sum F_{RI_f} + 0.6 \sum F_{RI_o} \quad (10)$$

where, F_{RI_f} is the forest areas (mixed forest, broad forest and conifer forest) and F_{RI_o} is the other land areas (residential area and road).

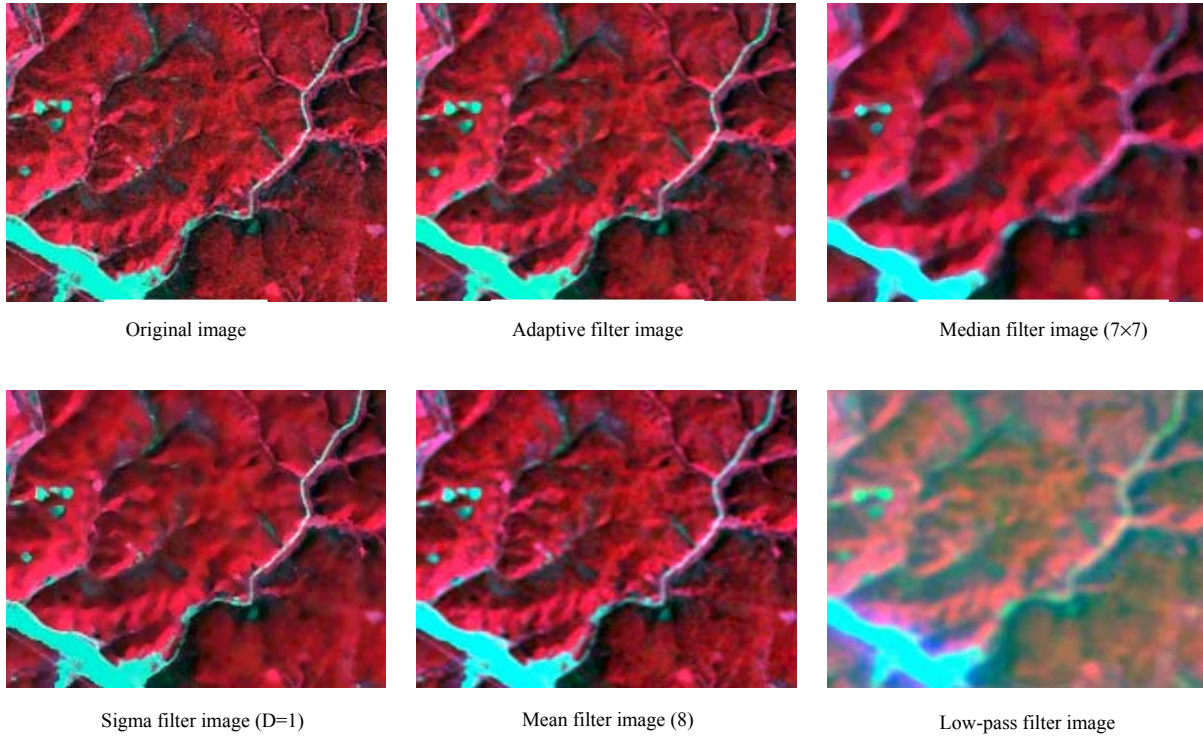


Fig. 1 Comparison of denoising methods for TM images

The values of P_{SNRI} are greater than 1 for all denoising schemes except the low-pass filter method. It indicates that the transformed images have good qualities. However, the values of E_{KRI} for each method vary greatly. And only the E_{KRI} value of sigma filter ($D=1$) method is greater than 1. The results indicate that only the sigma filter method ($D=1$) has the ability of strengthening the edge/boundary. Mean filter (4 neighborhood), median filter (3 by 3) and self-adaptive method ($E_{KRI}=0.85-0.88$) could preserve the edge/boundary information. The low-pass filter, median filter and the mean filter method ($E_{KRI}=0.51-0.54$) could not maintain edge and boundary information. Theoretically, low-pass method does not allow high frequency noises to pass. And edge/boundary information has high frequency changes. It is not a surprise that the edge/boundary information gets lost in the process. Self-adaptive filter method takes the weights as a self-adapted parameter, and the edge/boundary information can be maintained during the filtering process. The sigma filter method changed the calculated value in a squared window of 5 by 5 for the current value of the pixel. Therefore, the edge/boundary information becomes weak as increase of the enhance parameter D (Tables 1& 2).

To synthetically evaluate the ability of each denoising method, F_{EP} index ($F_{RI} - E_{KRI} - P_{SNRI}$) was designed. We know, to identify and classify TM images in forest areas, want to remove

scattered noise but to maintain and enhance the edge and boundary information through denoising process. So, in selection of the denoising method, the flattening ability became the most important since the major part in TM image shows forests with large distributing areas and scattered noise inside. The edge retaining ability is the second most important factor, which ensures the important boundary information for object identification and forest classification in TM image systems. The last important factor is the image quality, which offers help to optically classify object. The authors set $a=0.5$, $b=0.4$ and $c=0.1$ in F_{EP} in Equation (9). As shown in Table 2, F_{EP} values of the sigma filter ($D=1$) and enhanced self-adaptive filter methods are higher than that of other methods. The two filter methods can be considered to be suitable methods for denoising in TM image system for forest classifications.

The conclusion is supported by visual assessment of images processed by different denoising methods (Fig. 1). In the pictures denoised by sigma filter ($D=1$) and enhanced self-adapted filter method, the forest areas (conifer, broad leaved forest and mixed forest) show big speckles, but roads and residential areas disappear. It is of advantage to classifying forest areas. In other pictures, either the forest areas or roads and residential areas became dark, which severely disturbed the dividing of remote sensing picture in forest area.

Discussion and conclusions

Research results indicate that F_{RI} , E_{KRI} , P_{SNRI} and F_{EP} , can be combined to evaluate the effectiveness of different denoising methods. The determination of F_{EP} 's parameters should be dependent on the classification objectives. For the classification of forest types, selected denoising method should be able to filter out scattered noises while maintaining edge/boundary information. If we want to detect edge and boundary, the adjust factor b for index F_{EP} in Equation (9) should be high. We noticed that sigma filter ($D=1$) and the mean filter methods (4 neighborhood), are more suitable for edge detection. However, for pre-classified TM images of forest areas which need a strong flattening ability of denoised method, parameter a for index F_{EP} in equation (9) should be high. In this case, the mean filter (7×7) is more suitable.

From above analysis, it is concluded that the sigma filter ($D=1$) and enhanced self-adapted filter methods are suitable for preserving edge/boundary information and filtering out scattered noises. And these two filtering methods are the best denoising methods for TM image of forest areas.

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